

DRYING CONDITION EFFECTS ON FLUIDIZATION QUALITY AND FLUIDIZATION VELOCITY AT INITIAL AND FINAL STAGES OF CUBICAL PARTICULATES FOR PET FOOD

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ABSTRACT

In this research fluidization behavior of cubical Bovine intestine samples was studied. Bovine intestine samples were heat pump dried at atmospheric pressure and at temperatures below and above the material freezing points. Experiments were conducted to study fluidization characteristics and drying kinetics at different drying conditions. Bovine particles were characterized according to Geldart classification and minimum fluidization velocity was calculated using Ergun Equation and generalized equation for all drying conditions at the beginning of the trials and end of the trials. Walli's model was used to categorize stability of the fluidization at the beginning and end of the drying for each trial. Walli's values determined were positive at the beginning and end of all trials indicating stable fluidisation at the beginning and end for each drying condition.

INTRODUCTION

The use of fluidization is one of the main applications in drying of agro-food materials. When an air stream is passed through a free flowing material resting on a permeable support, the bed starts to expand when a certain air velocity is reached. The superficial velocity of the air at this stage is the minimum fluidization velocity, with continual increase in air velocity, a stage is reached where the pressure across the fluidised bed drops rapidly, and the product is carried along the stream. The velocity at this stage is known as the terminal velocity. During fluidization operations the superficial velocity of the air should remain between minimum fluidization velocity and terminal velocity (Senadeera et al., 1998 and Senadeera, 2009). Depending on the particle density, air

density and size and shape of the material, they can be categorized according to the type of fluidization behavior by the use of Geldart Classification (Geldart, 1973).

Fluidised bed drying has been recognized as a gentle uniform drying process down to low residual moisture content with a high degree of efficiency (Borgotte and Simon, 1981). In fluidized bed, conditions are favourable for rapid heat and mass transfer due to thin boundary layer surrounding the food particles due to very rapid mixing. This is a very convenient method for heat sensitive food materials as it prevents them from over-heating (Giner and Calvelo, 1987).

The Ergun equation (Ergun, 1952) is the widely accepted model to determine minimum fluidization velocity of a fluid to fluidise any material (Kuni and Levenspiel, 1969).

$$(1-\epsilon_{mf})(\rho_p - \rho_f)g = 150 \frac{(1-\epsilon_{mf})^2}{\epsilon_{mf}^3} \frac{\mu u_{mf}}{(\phi d_p)^2} + 1.75 \frac{(1-\epsilon_{mf})}{\epsilon_{mf}^3} \frac{\rho_f u_{mf}^2}{\phi d_p} \quad (1)$$

The values for minimum fluidization velocity obtained by the Ergun Equation are mostly reliable for spherical and relatively small particles. For larger particles which comprise of various shapes and sizes Ergun values does not confirm to the experimental values (McLain and McKay, 1980). For the cases of larger particles at higher Reynolds numbers ($Re > 1000$) fluidization behavior is mainly governed by the kinetic energy term in the Ergun Equation. Hence the Ergun equation can be simplified to (Kunii and Levenspiel, 1969):

$$u_{mf}^2 = \frac{\phi d_p^2 (\rho_p - \rho_f)}{1.75 \rho_f} g \epsilon_{mf}^3 \quad (2)$$

For wide variety of systems it was found that the value $1/\phi \epsilon_{mf}^3$ equals to 14 (Wen and Yu, 1966) and a generalized equation can be applied to predict u_{mf} for larger particles when $Re > 1000$.

$$u_{mf}^2 = \frac{d_p (\rho_s - \rho_f)}{24.5 \rho_f} g \quad (3)$$

where, ρ_s – particle density (kg/m^3), ρ_f – fluid density (kg/m^3), u_{mf} – minimum fluidization velocity (m/s), d_p – particle equivalent diameter (m), Re – Reynolds number

Properly selected heat pump drying technology is an environmental friendly technology. It is operated in a closed drying circuit hence there won't be any gas or fines discharge to the atmosphere. The drawback of the heat pump technology is the low moisture removal rates for atmospheric pressure freeze drying with greater residence times for stationary beds. This problem can be overcome by agitation, fluidization and intermittent drying (Mujumdar and Alves-Filho, 2003).

Any drier that uses convection as the primary mode of heat input can be fitted with a suitably designed heat pump such as fluid bed dryers. Heat pump fluid bed drying offers better product quality, offsetting incremental increasing in drying costs with a high market value of the product (Alves-Filho and Strommen, 1996).

Prediction of fluidization behaviour is needed for the best working condition of a product in a fluidization system (Khoshtaghaza and Chayjan, 2007). The best condition for fluidization is at minimum fluidization velocity where more energy savings could be observed. In any system finding of minimum fluidisation velocity is a necessity to optimize its operation. Also fluidization quality is necessary to carry out this operation smoothly. Wallis's criteria is a good way of finding quality of fluidization when homogenous particles are concerned (Gibilario, 2001) and used by some authors (Khoshtaghaza and Chayjan, 2007).

Wallis's model was used as the fluidization stability criteria as suggested by Gilbilaro(2001) and given by Equation 4.

$$\frac{1.79}{n} \left(\frac{gd_p}{U_t^2} \right)^{0.5} \left(\frac{\rho_p - \rho_f}{\rho_p} \right)^{0.5} \left(\frac{\epsilon_{st}^{1-n}}{(1-\epsilon_{st})^{0.5}} \right) - 1 = V_e \quad (4)$$

The value of Walli's factor V_e is used to categories the quality of fluidization.

$V_e > 0$ stable fluidization (homogeneous)

$V_e = 0$ stability limit

$V_e < 0$ unsatble fluidization (bubbling)

The Richard-Zaki coefficient 'n' is derived according to Equation 5, and used in Equation 4.

$$\frac{4.8 - n}{n - 2.4} = 0.043 Ar^{0.57} \quad (5)$$

Archimedes number Ar (Equation 6) was used to calculate terminal velocity (U_t) and Richard-Zaki coefficient together with Equation 7 and 8.

$$Ar = \frac{gd_p^3 \rho_f (\rho_p - \rho_f)}{\mu_f^2} \quad (6)$$

$$Re_t = \left[-3.809 + \left(3.809^2 + 1.832 Ar^{0.5} \right)^{0.5} \right]^2 \quad (7)$$

$$Re_t = d_p U_t \rho_f / \mu_f \quad (8)$$

Knowledge of drying kinetics is important in the design, simulation and optimization of the drying processes. Drying curves are usually modeled by defining the drying rates constants based on first order kinetics. The basic model of drying kinetics is known as the simple (exponential) model (Equation 9).

$$MR = \exp (- kt) \quad (9)$$

Where MR = moisture ratio, k = drying constant and t = drying time.

Not much literature available at the time of investigation concerning the systematic experimental investigation of fluidization behavior of bovine intestine particles. This is an experimental investigation to assist understanding, design and development of fluidsation processes for drying of food material such as Bovine Intestine particles. Bovine intestine is rich in lipids and minerals important in Carnivores diet used in pet food. The heat pump drying is a gentle process to remove moisture from the raw material and preserve the chemical constituents. The dried BI has a great potential for application in the pet food market. The procedures developed can be used as the basis for general predictive correlations to study the behaviour of food material concerned.

The objective of this work on fluidized bed heat pump drying of bovine intestine is to study the effect of operating conditions on the fluidization characteristics and its effect on the drying kinetics. Also compare the minimum fluidization velocity with the generalized model and Ergun model and confirm stability of the fluidization during experiments.

MATERIAL AND METHODS

Raw materials

Bovine intestine was used for producing cubicle particles. Samples were prepared by cutting them into 4 mm cubes and kept at -25° C before drying to maintain original characteristics and heated close to melting point prior to drying.

Drying

The heat pump dryer dehumidifier system connected to the fluidized bed dryer in the Department of Energy and Process Engineering at Norwegian University of Science and technology used for the experimentation. The dryer has a drying loop and heat pump circuit. The drying loop has an air dehumidifier and heater and a blower. The conditioned air enters the chamber, contacts and fluidized the wet materials. The removed water from the material was condensed on the surface of the evaporator and was drained out from the loop. The dehumidified air flowed through the condenser and was heated and re-enter the drying chamber at the desired drying temperature. In this way the latent heat of removed water is used to boil the fluid inside the evaporator. The energy recovered is transferred to the air flow as the fluid liquefies inside the condenser. The external parts of the drying loop and heat pump circuit are thermally insulated to minimize energy losses to the surroundings (Alves-Filho et al., 2006). Schematic of the drying loop is shown in Figure 1 and Fig 2 shows the experimental setup.

The drying chamber is cylindrical with a diameter of 0.25 m, and particle bed height was kept at constant for all trials by using a bed volume of $2 \times 10^{-3} \text{ m}^3$ of material. The drying temperatures were -10, -5, 5, 15, 25°C and combinations of -10/25°C and -5/25°C. All experiments were done under stable fluidization condition and fluidization velocity was kept at 1.5~2.5 m/s. Fluidised bed heat pump drying of bovine intestine samples were done in atmospheric pressure at below and above the material freezing temperature. Sampling and measurements were taken during each drying test to characterize quality and properties.

Material characterization

Some important particle characteristics of the bovine intestine are described below. The equivalent diameter given in here is the diameter of a sphere having the same volume as the particle (Table 1).

Table 1. Material characteristics

Property	Value
Initial particle density	990 kg/m ³
Final particle density	1100 kg/m ³
Initial bulk density	200 kg/m ³
Final bulk density	500 kg/m ³
Initial bed porosity	0.49
Final bed porosity	0.81
Sphericity	0.81

Physical property measurement

To determine particle density, a known number of particles were weighed and, their volume was determined using volume displacement method. For bulk density, similar method was used by filling a container of known volume. Particle diameter and sphericity was calculated from initial dimensions of the product. Particle density and bulk density was used to calculate bed porosity at both initial and final conditions for all drying conditions.

Analysis of experimental data and modeling

Particle characteristics were used to calculate minimum fluidization velocity at the beginning and ending of the experiments. In these calculations volume shrinkage was not considered and assumed particle shape remains the same through out entire drying period. Both Ergun values and generalized values were calculated using Equations 1 and 3 .

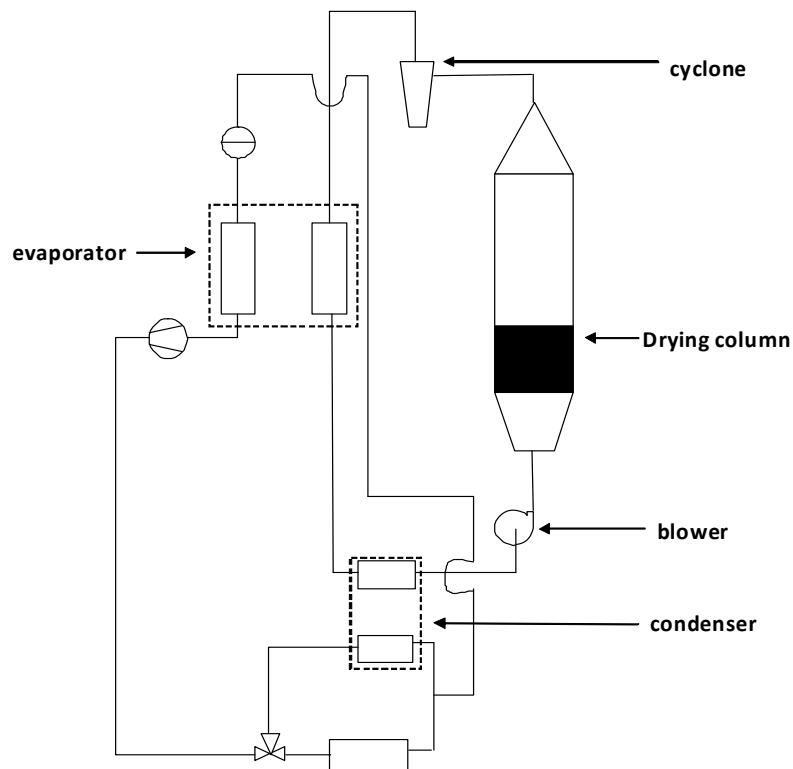


Figure 1. Schematic of the drying loop



Figure 2. Experimental fluid bed heat pump dryer

RESULTS AND DISCUSSION

Fluidisation Characteristics

Figure 3 shows initial and final particle classification in the Geldart chart. Particles lie in the Geldart D category showing characteristics similar to grains which can be fluidized in shallow beds or in spouted beds. When drying proceeds its position moved from right to left in the chart showing its fluidizability increase for all the drying conditions considered. This may be attributed to changing of particle sphericity from 0,81 to a value closer to 1. Fig 2 only two points are visible but actually initial and final characteristic points are very close to each other and appeared as a one point in the chart.

There was an increase in minimum fluidisation velocity at very low moisture values this can be probably attributed to an increase in the particle density due to shrinkage and interlocking of particles in the fluid bed. The change in minimum fluidization velocity might not only be due to the reduction in moisture content, other physical changes (such as geometrical shape and dimensions) could also have contributed to this effect.

Low value of bulk density (200 kg/m^3) at the end of drying compared to initial bulk density of 500 kg/m^3 and higher particle density at the end of drying (from 900 kg/m^3 initially and 1100 kg/m^3 finally) is attributed to difference in shrinkage producing a very porous product.

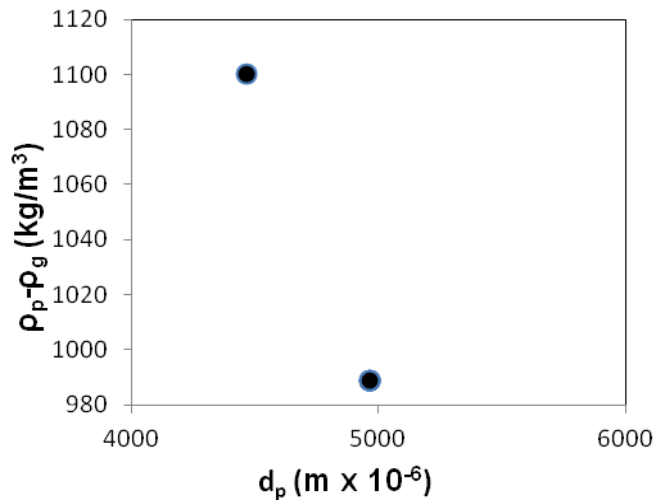


Figure. 3. Particle Classification according to Geldart chart

Quality of fluidization

Stability criterion value of Walli' model V_e varies between 0.5641~0.6488 at initial and final stages of all drying conditions. Those are positive values and according to Walli's criterion material shows stable fluidization. The visual observation during experimentation also confirmed good fluidization.

Modelling of minimum fluidization velocity

The behavior of minimum fluidization velocity calculated by Ergun equation and generalized equation are with respect to drying conditions are shown in Figure 3 and calculated values are given in Table 2. When using the Ergun model a sphericity values was calculated based on measured dimensions of the Bovine intestine particles during drying and comparing it with equivalent diameter given by the volume of the particle. Fluidization behavior of the particles, change progressively with temperature of drying as the drying proceeds. Experimental values were kept at 1.5~2.5 m/s and calculated Ergun values changed from 1.35 to 2.33 m/s. Generalized model predicted velocities underestimate minimum fluidization velocity at higher drying temperatures.

Table 2. Minimum fluidization velocity (m/s)

T (°C)	Ergun Model (calculated)		Generalised Model (calculated)		Experimental
	Initial	Final	Initial	Final	
-10	1.35	2.2	1.21	1.27	1.5~2.5
-5	1.36	2.22	1.22	1.28	
5	1.38	2.26	1.24	1.31	
15	1.4	2.29	1.26	1.33	
25	1.42	2.33	1.28	1.35	

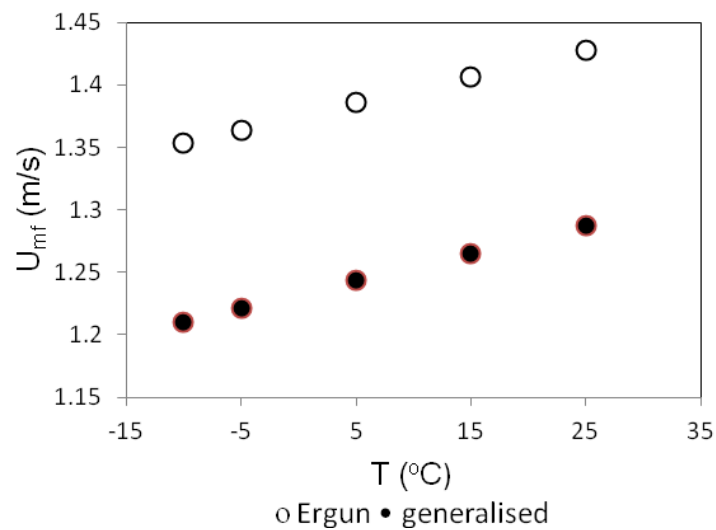


Figure 4. Initial fluidisation behavior (calculated).

It was found that the difference in initial fluidisation velocity and final fluidisation velocity calculated using Ergun Equation showed a linear trend with the drying temperature. The behavior of difference in initial fluidization velocity values with temperature of drying is shown in Figure 5.

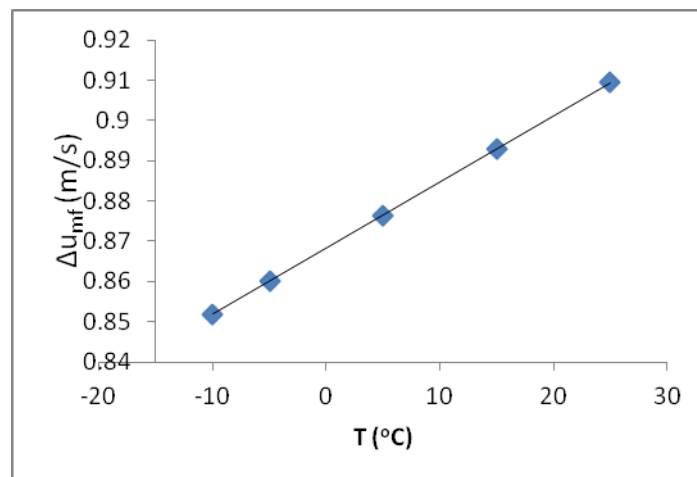


Figure 5. Difference in fluidization velocity with drying temperature.

The relation between difference in initial and final fluidization velocity is linearly correlated to the following equation.

$$\Delta U_{mf} = 0.8683 + 0.0016 T \quad (10)$$

where, U_{mf} is the minimum fluidization velocity and T is the drying temperature.

CONCLUSIONS

This work showed modeling of minimum fluidization velocity of small Bovine Intestine particles in fluid bed dryer at different drying conditions. Fluidization behavior of the Bovine intestine particulates change progressively as the drying proceeded. The calculated minimum fluidization with both Ergun Equation and Generalised equation based on physical changes gave values confirm with the experimental values used. Both methods can be applied to predict minimum fluidization velocity with a reasonable accuracy. It is important to understand the changes, so that airflow during drying can be controlled to achieve an optimum fluidization. Further experiments are necessary to investigate the relation between bed heights and minimum fluidization velocity of Bovine Intestines.

NOTATION

A, B, C	constants	
d	equivalent diameter	m
D	diameter	m
g	acceleration due to gravity	m/s ²
L	length	m
m	moisture content (dry basis)	kg/kg db
Re	Reynolds number	
T	temperature	°C
u	velocity	m/s

Greek Symbols

ϕ	sphericity	
ε	porosity	
ρ	density	kg/m ³
μ	viscosity	N s/m ²

Subscripts

f	fluid
mf	minimum fluidization
p	particle
s	solid

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